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Vibration Qualification of Electronic Instrumentation for Underground Coal Mining Machinery

By Roy C. Bartholomae, Bruce S. Murray,
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UNITED STATES DEPARTMENT OF THE INTERIOR

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VIBRATION QUALIFICATION OF ELECTRONIC INSTRUMENTATION FOR UNDERGROUND COAL MINING MACHINERY

By Roy C. Bartholomae,[1] Bruce S. Murray,[2] and Richard Madden[3]

ABSTRACT

An accurate characterization of the vibration environment and a vibration qualification test derived from it will be a very useful tool for manufacturers of instrumentation for use on underground coal mining equipment. Recognizing this, the Bureau of Mines sponsored a study wherein vibration levels were measured on mining equipment to form a basis for developing the required vibration test. The data base was composed of 160 samples taken at different positions on a variety of underground machinery. The data were analyzed and presented in a format typical of military vibration qualification tests. The form was shown to be virtually identical to the swept sine test envelope specified in MIL-STD-810B for tracked vehicles.

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INTRODUCTION

The desire for increased production of coal, together with the growing emphasis on health and safety in underground coal mines, means that additional electronic instrumentation will be needed on underground mining machines. To insure long-term reliable operation of such instrumentation in the harsh environment of underground mines, manufacturers must consider the effects of vibration at the design stage. A useful tool for the instrument designer is a vibration qualification test, preferably one designed to meet an existing military standard, because many commercial laboratories are already set up to perform testing to meet military standards.

This Bureau of Mines report describes the development of a vibration qualification test and compares the test with similar ones used by the armed forces.

DATA BASE

The first step in developing the vibration qualification test was to create a data base. Under U.S. Bureau of Mines Contract H0155113, data were taken on 30 mining machines of 8 different types, including continuous miners, loaders, cutting machines, track jeeps, face drills, shuttle cars, roof bolters, and scoop trams. Vibration measurements were made at a variety of positions on each machine, resulting in a total of 160 samples in the data base. Data were recorded on magnetic tape and then analyzed in 1/3-octave bands in the frequency range between 3.2 and 500 Hz. A typical sample of data taken on a continuous miner is shown in figure 1.

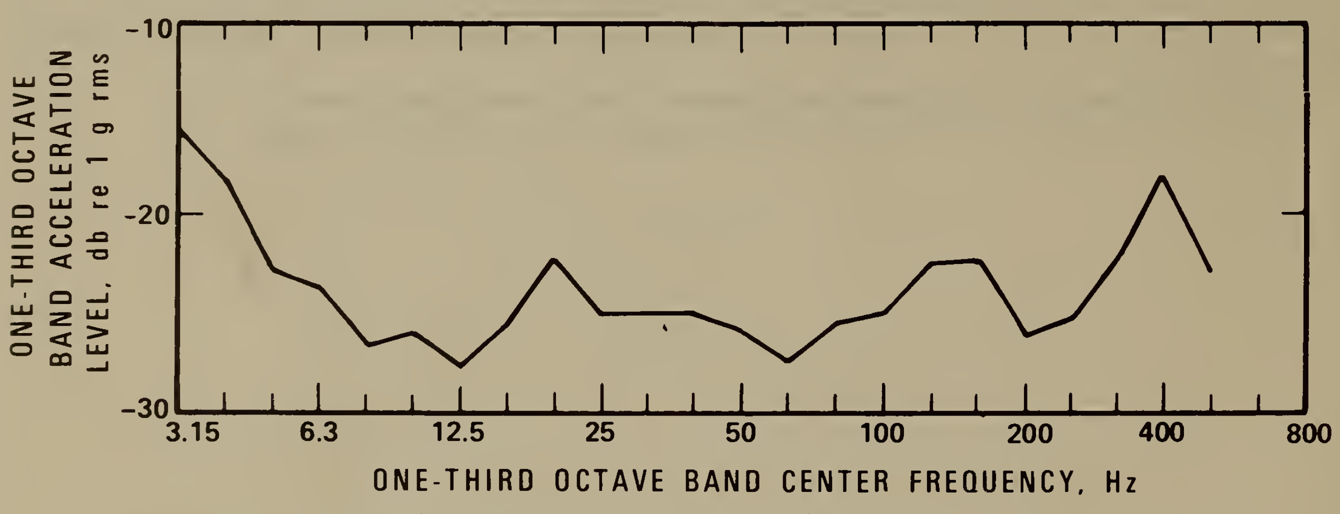

FIGURE 1. - Horizontal acceleration on main frame of continuous miner during loading.

DATA ANALYSIS

Data from each of the samples were combined to form a 160-sample data set in each of the 23 1/3-octave bands between 3.2 and 500 Hz. The following analysis was used to convert the data base into a usable vibration qualification test.

Qualification tests are customarily based upon the highest vibration levels encountered in service. The highest level can be estimated as that level which is not exceeded either more than 1 time in 100 (99^{th} percentile) or more than 1 time in 1,000 (99.9^{th} percentile). Our 160-sample data base is clearly too small in itself to determine these low-probability occurrences. If, however, the 160-sample data base is representative of a larger well-defined data base, we can determine either or both of these percentiles with confidence. Fortunately, we are able to show that a normal distribution curve well represents the data. We illustrate this by constructing an amplitude histogram from the samples in each 1/3-octave band and comparing it to the normal distribution. The histogram was formed by grouping the data in ten 5-db steps in the acceleration level range from -40 db re 1 g (0.01 g)[4] to +5 re 1 g (1.78 g).

The total number of samples in each histogram equals the total number of recordings (that is, 160). In cases where data fell below the noise level of the measurement system, these data were grouped with the -40 db re 1 g (0.01 g) data.

As an example, the histogram for the 160-Hz 1/3-octave band is presented in figure 2. The number of occurrences in each 5-db step is given by the ordinate to the left, and the associated probability of occurrence is given on the right.

The cumulative percentage distribution is plotted on normal distribution paper in figure 3. Since a straight line fits the data very well, the data can be considered normal. Note that deviations from the line at the end points are not significant; that is, at lower levels, data below the noise floor were grouped with the -40 db re 1 g data, and at the high end there is only one sample greater than 0 db re 1 g. The mean for this sample is given by the 50^{th} percentile as -22.5 db, and the standard deviation is 10.5 db.

Extrapolation based upon a normal distribution with a mean of -22.5 db re 1 g and a standard deviation of 10.5 db gives the 99^{th} and 99.9^{th} percentiles (rounded to the nearest 0.5 db) as

$$AL_{99.9} = \mu + 3.1\sigma = 10 \text{ db re } 1 \text{ g}$$

and $$AL_{99} = \mu + 2.33\sigma = 2 \text{ db re } 1 \text{ g}.$$

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[4]Acceleration level equals 20 $\log_{10}$ (acceleration in g's).

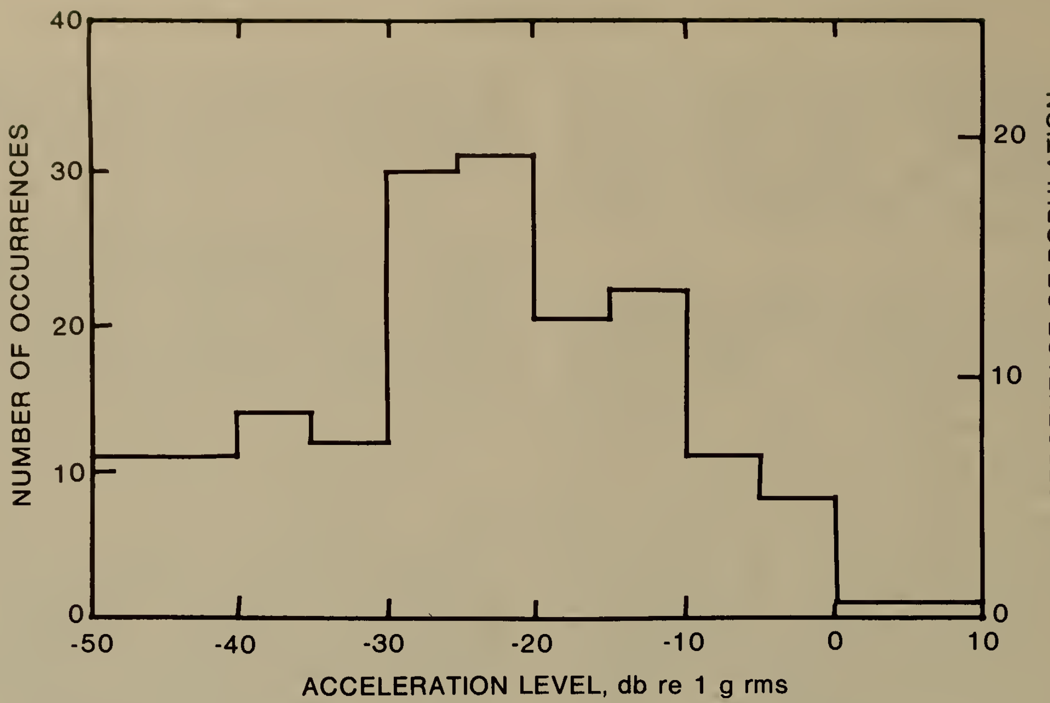

FIGURE 2. - Acceleration level distribution in the 160-Hz 1/3-octave band.

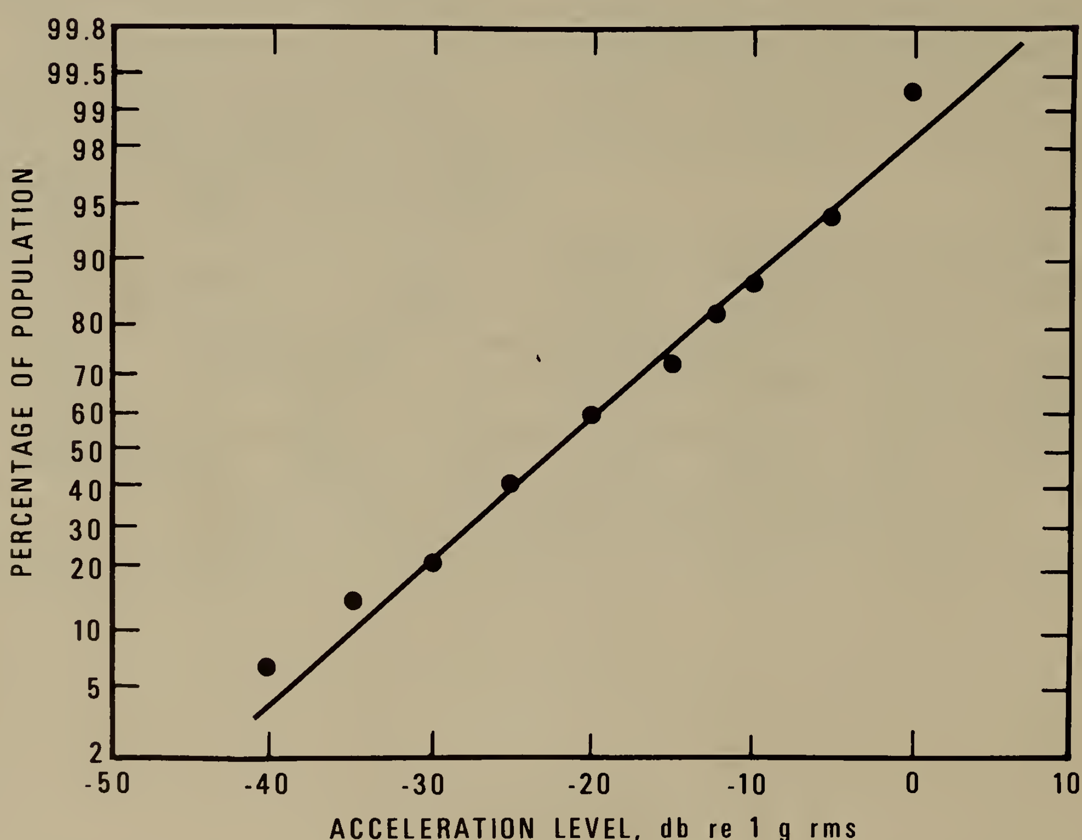

FIGURE 3. - Cumulative probability of acceleration level in 160-Hz 1/3-octave band.

A similar analysis was performed for data in each of the 1/3-octave bands, and in each case the distribution was normal. The mean, standard deviation, and 99^{th} and 99.9^{th} percentile values for each 1/3-octave band are listed in table 1 and plotted in figure 4. It is important to remember that these values describe the statistics of the samples from each 1/3-octave band and that they do not describe an expected spectrum shape. Rather, the data provide an overall envelope upon which to base qualification tests. Also plotted in figure 4 are the maximum values recorded in each of the 1/3-octave bands. Note that a majority of these values fall between the 99^{th} and the 99.99^{th} percentile values, as expected from the 160-point sample size, thus providing a limited validation of the approach.

TABLE 1. - 1/3-octave band acceleration level statistics

1/3-octave band center frequency, Hz	Acceleration level, db re 1 g rms			
	Mean	Standard deviation	99th percentile	99.9th percentile
3.2	-18	9.5	+4	+11.5
4.0	-20	9	+1	+8
5.0	-21	11	+4.5	+12
6.3	-21.5	11.5	+5.5	+14
8.0	-23.5	8.5	-4	+2.5
10	-25	10.5	-.5	+7.5
12	-25	9.5	-.5	+4.5
16	-26	10.5	-1.5	+6.5
20	-25	9.5	-3	+4.5
25	-23.5	8.5	-1.5	+3
32	-24	10	-.5	+7
40	-24.5	13	6	+15
50	-24	11	+1.5	+10
63	-25	12.5	+4	+13.5
80	-23.5	11	+2	+10.5
100	-23.5	10	0	+7.5
125	-22.5	10	+1	+8.5
160	-22.5	10.5	+2	+10
200	-22	10	+1	+9
250	-20	10	+3.5	+11
315	-17	11.5	+10	+18.5
400	-17.5	12	+10.5	+19.5
500	-17.5	11.5	+9.5	+18

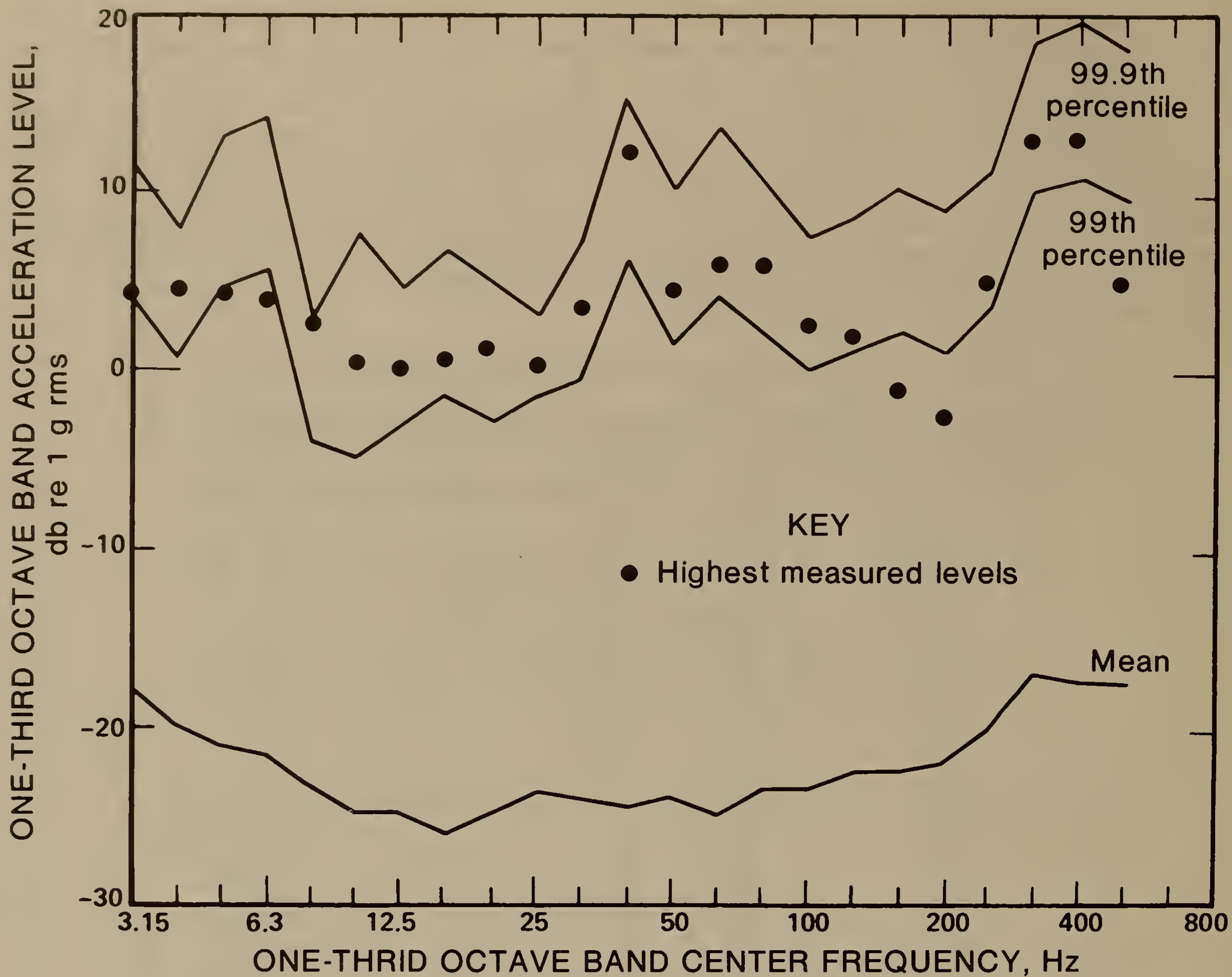

FIGURE 4. - Summary of statistics of acceleration levels for underground mining machines.

DEVELOPMENT OF VIBRATION QUALIFICATION TESTS

Virtually all the vibration qualification tests conducted in the United States are based on Military Standards (MIL-STD) developed over many years. These standards reflect experience in a vast number of environments. It is reasonable, therefore, to base any vibration tests upon the military standards, at least initially, and amend them later if necessary to meet particular requirements. Another major benefit of the use of military standards relates to test equipment performance and limitations. The development of these standards as viable test procedures has been closely linked with the attainable performance of readily available shakers and associated hardware. Thus, specification of MIL-STD levels will assure that the tests are experimentally possible.

With these considerations in mind, we reviewed four pertinent military standards to determine their suitability for the underground mining equipment.

The vibration qualification standards reviewed were MIL-STD-167, MIL-STD-810B, MIL-STD-810C, and MIL-E-5272-C.

Although many other standards include vibration test procedures, these four provided data for a wide range of applications. MIL-STD-167 provides data on shipboard vibration levels; MIL-STD-810 is the U.S. Air Force environmental test procedure for flight and ground vehicles; and MIL-E-5272-C is concerned with environmental testing of equipment destined for aircraft, ship, and missile applications.

The review consisted of evaluating the vibration test specifications in each of the Military Standards against the measured and predicted vibration levels of underground mining equipment. Figure 5 presents a summary of the vibration spectra specified for swept sine tests in the MIL-STD's reviewed. The spectra shown for MIL-E-5272-C and MIL-STD-167 are the highest levels indicated in that particular specification. However, in the case of MIL-STD-810B and MIL-STD-810C, we have presented the most appropriate spectrum based on the description in the standard "tracked vehicles." Note that these spectra are presented with the measure of vibration amplitude being "displacement (peak-to-peak) inches" rather than "db re 1 g rms."

The basic expression used to convert vibration amplitude from acceleration (in db re 1 g rms) to displacement (in inches peak to peak), assuming that the vibration is sinusoidal, is given by

$$\text{D.A.} = \frac{2\sqrt{2}\,g}{(2\pi f)^2}\,10^{a/20}$$

where D.A. = displacement (peak-to-peak), inches, a = acceleration (db re 1 g rms), f = frequency (Hz), and g = 386.4 (in/sec^2).

This expression reduces to

$$\text{D.A} = 10^{a/20} \times \frac{27.68}{f^2}.$$

As an example, we calculate the displacement produced by the 99.9th percentile acceleration at 160 Hz from the data in table 1:

$$\text{D.A.} = 10^{10/20} \times \frac{27.68}{(160)^2} = 0.0034 \text{ in.}$$

Figure 6 presents a summary of the vibration levels expected on underground mining machines, the displacement values being derived from the data given in table 1. The open circles represent the vibration amplitude that will only be exceeded 1 time in 1,000 and the closed circles show the amplitudes that will be exceeded 1 time in 100. We have also plotted the MIL-STD-810B level for tracked vehicles, and it is seen to be a good match over virtually all the frequency range except below 8 Hz. The other specifications plotted in figure 5 do not provide a suitable match to the plotted points.

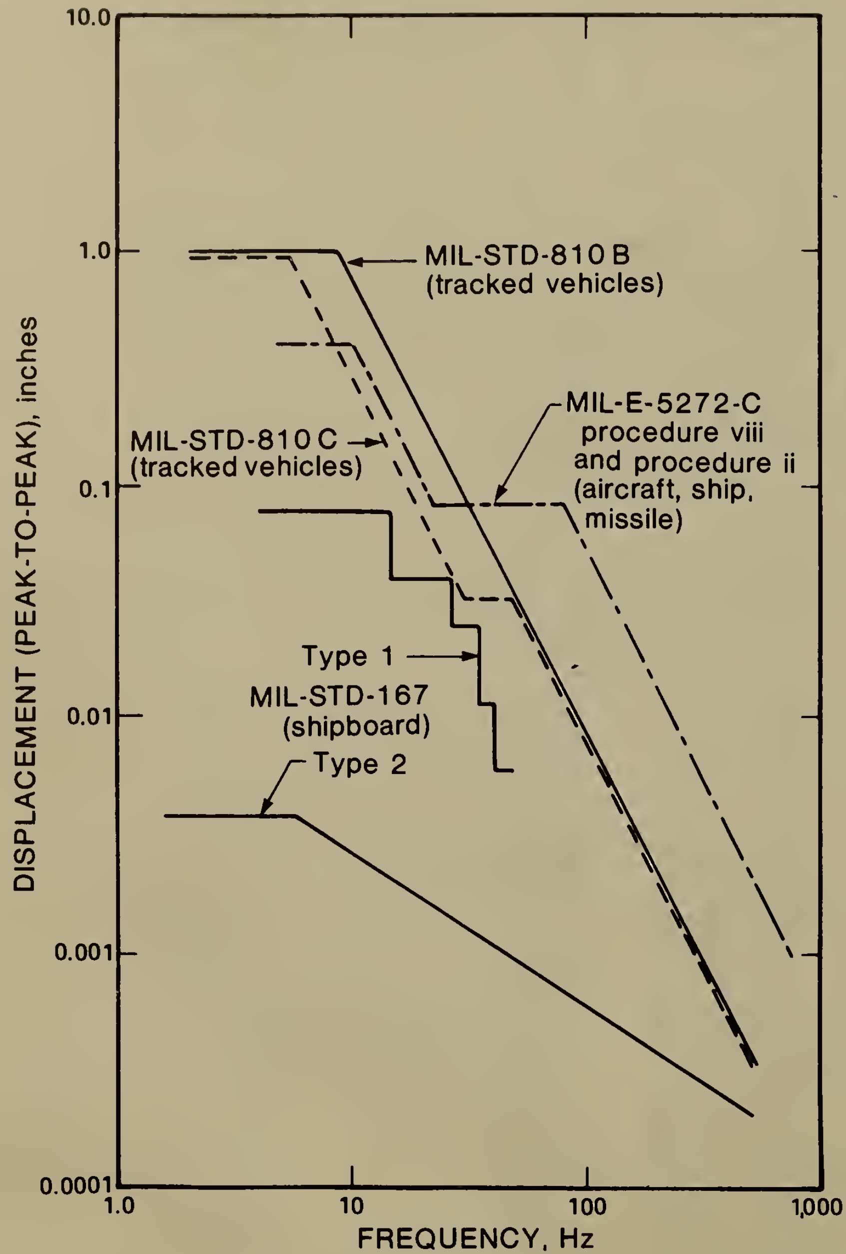

FIGURE 5. - Summary of swept sine vibration qualification tests issued by the military.

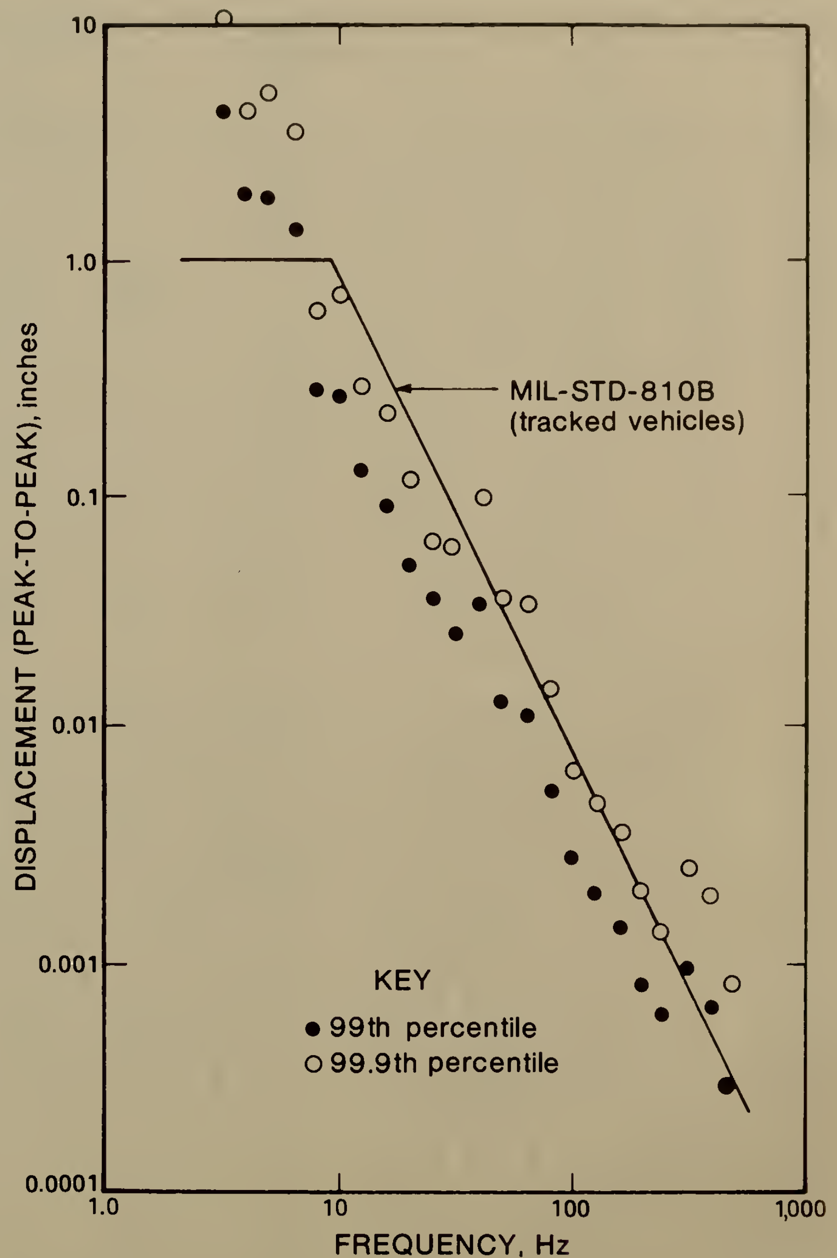

FIGURE 6. - Comparison of underground mining machine vibration data with MIL-STD-810B.

DISCUSSION

The deviation of the standard below 8 Hz is most likely due to the normal displacement limitations of commercial shakers. This is an example of a specification being tailored to fit the available equipment so that the testing can be performed economically. It is likely that the tracked vehicles considered by MIL-STD-810B have low-frequency vibration amplitudes much like those plotted in figure 6. Since the displacement-limited curve satisfactorily tests the equipment of these vehicles, we may conclude that it will do the same for the equipment on underground mining machinery. Therefore, we recommend that the MIL-STD-810B vibration tests curves for category f equipment be employed, using curve W.

It should be noted that MIL-STD-810B, issued in June 1967, is not the latest issue of this standard; it is used because MIL-STD-810C, issued in 1975, specifies a different vibration test for components on tracked vehicles that does not adequately simulate the expected levels on mining equipment. The specification set in issue B is equivalent to a ±4 g level from 9 to 500 Hz. The specification in issue C is ±1.5 g from 5.5 to 30 Hz and ±4.2 g from 50 to 500 Hz. The reason for the reduction in levels below 50 Hz is not known.